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# Application of Sectorised Antennas and STBC to Increase the Capacity of Hot Spot WLANs in an Interworked WLAN/3G Network

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**Abstract**— At present, Wireless Local Area Networks (WLANs) supporting broadband multimedia communication are being developed around the world. Standards include HIPERLAN/2, and the IEEE 802.11 family. These systems provide channel adaptive data rates up to 54 Mbps over short ranges up to 200 meters. It is likely that WLANs will become an important complementary technology to 3G cellular systems and will typically be used to provide ‘hot-spot’ coverage. In this paper, the complementary use of WLANs with and without sectorised antennas in conjunction with UMTS is presented. Additionally, results are presented for the case where STBC (Space Time Block Codes) are considered as a means of enhancing WLAN performance. It is shown that significant enhancements in both coverage and capacity can be achieved in both cases.

**Keywords:** WLANs, hot-spot, interworking, HIPERLAN/2.

## I. INTRODUCTION

WLAN standards such as HIPERLAN/2 [1,2], and 802.11a/802.11g [12,2], are expected to become an important complementary technology to 3G cellular systems and will typically be used to provide ‘hot-spot’ coverage. In [3], in order to quantify the capacity enhancement benefits offered to a cellular network by wireless LAN technology, we applied novel ray-tracing, software-simulated physical layer performance results and optimal base-station deployment analysis to inter-networking. In this paper, we will expand our analysis for the case where WLANs employ sectorised antennas. Sectorised antennas will be considered in order to improve the performance of WLANs. A selective diversity scheme has been employed that monitors the signal level on all antennas and selects the strongest at any time [4]. Additionally, performance results will be shown for the case where STBC are considered as a means of enhancing the performance of OFDM WLANs. These two approaches will be compared with the case of a standard WLAN system.

Presently, two approaches have been proposed for the interconnection of WLAN and 3G networks, namely: tight coupling and loose coupling [5]. Within the context of 3G systems, WLANs are a complementary technology that can be used to provide users with high data-rate services in localised areas. Handovers will be possible between 3G cellular access networks and WLAN access points. A number of existing

solutions have been identified from organizations such as Lucent [13] and Fujitsu, and other similar solutions are expected to emerge in the near future. A user with a dual mode terminal will be able to take advantage of the higher data rates offered by the WLAN and the full range of 3G networks.

To study the use of hot spot WLANs to enhance the performance of 3G cellular networks, we will focus on a dense urban environment where capacity requirements are at their highest. To quantify the problem, the simulated deployment of a high capacity 3G network will be performed together with a wireless LAN hot spot overlay similar to [3].

## II. THE SIMULATION SETUP

This paper assumes the use of UMTS technology at 2GHz and HIPERLAN/2 WLAN technology at 5GHz. However, due to the similarity of the physical layers [2], a number of the results can be applied to IEEE 802.11a. A number of simulation tools previously developed by the authors were combined in order to evaluate potential coverage and capacity gains. These include: a) a propagation modelling tool, b) a site optimisation tool, and c) a WLAN physical layer simulator enhanced with the use of sectorised antennas or STBC techniques. Each of these algorithms is described in the following subsections.

### A. The Propagation Model

A state of the art deterministic propagation model is used to provide the channel data required in the evaluation of both the 5GHz WLANs and 2GHz cellular networks [3,7]. Propagation data is supplied for each potential site. This data is then provided as an input to the site optimisation module and is used to optimise the number and locations of sites. Complex channel impulse response (CIR) data from the propagation model at the optimised WLAN access points is additionally provided and used in the physical layer simulations.

### B. Site Optimisation Module

A novel optimisation algorithm that allows the optimum positioning of cellular and WLAN sites has been implemented. This algorithm is based on a combinatorial approach previously developed for conventional cellular planning [3, 6]. For the

deployment of WLAN hot-spots, potential access point (AP) locations were selected from available lamppost locations, while conventional locations were used for the deployment of UMTS base stations. The 3G study was performed at 2GHz, assuming omni-directional antennas located at a height of 5m and with a transmit power of 30dBm. The hot-spot overlay was performed at 5GHz, with antennas at a height of 5m. 7 UMTS BSs were chosen to fulfill the coverage requirements of the area (90% coverage). 3 WLAN sites were chosen to cover key sections of the main commercial/business area—see Figure 8.

### C. Physical Layer Simulator for WLANs

In order to evaluate the performance of the WLAN hot-spots in an outdoor environment, link level simulations were performed utilising channel information from the propagation model with and without sectorised antennas. A detailed physical layer (PHY) software simulation of HIPERLAN/2 and 802.11a has been developed previously by the authors and results were presented in [2]. This simulator was enhanced by adding sectorised antennas [4] and STBC [8] algorithms. For the purposes of this paper, the software simulation was employed to evaluate performance in terms of Packet Error Rate (PER) and throughput versus Signal to Noise Ratio (SNR) for the channels provided by the propagation model.

The physical layers of HIPERLAN/2 and IEEE 802.11a/g are based on the use of OFDM. OFDM modulation is implemented by means of an inverse FFT. 48 data symbols and 4 pilots are transmitted in parallel in the form of one OFDM symbol. Importantly, the physical layer provides several modes each with a different coding and modulation configuration [2] (Mode 1: BPSK 1/2 rate, Mode 2: BPSK 3/4 rate, Mode 3: QPSK 1/2 rate, Mode 4: QPSK 3/4 rate, Mode 5: 16QAM 9/16 rate, Mode 6: 16QAM 3/4 rate, Mode 7: 64QAM 3/4 rate). These are selected by a link adaptation scheme. The link throughput when retransmission is employed is given by:  $Throughput = R(1-PER)$ , where  $R$  and  $PER$  are the bit rate and packet error rate for a specific mode respectively [2]. In this paper, a link adaptation scheme has been used in which the mode with the highest throughput is chosen for each instantaneous SNR value. To obtain the throughput after the Medium Access Control (MAC) layer, MAC overheads are also considered [2, 9].

### III. SECTORISED ANTENNAS

The use of sectorised antennas is common in many wireless applications. Firstly, an antenna gain is achieved due to the smaller azimuth beamwidth of the sectored antenna. Secondly, spatial filtering of the channel is achieved; typically resulting in a perceived channel that has a reduced delay spread and improved Rician statistics, if the sector with the strongest signal level is chosen. In this paper a 60° switched sectorised antenna at the AP with a selective diversity scheme has been assumed that monitors the signal level on all antennas and selects the strongest at any time. The HIPERLAN/2 MAC provides explicit support for the use of sectorised antennas at the AP. This is achieved by transmitting separate control sequences for each sector employed [9]. However, the additional control transmissions represent an additional

overhead in the MAC frame. The 802.11a standard [12] does not support the use of sectorised antennas.

### IV. SPACE TIME BLOCK CODES

In [10] Alamouti proposed a simple transmit diversity scheme which was generalized by Tarokh [11] to form the class of STBC. These codes achieve the same diversity advantage as maximal ratio receive combining (allowing for a 3dB degradation for the case of 2 Tx antennas due to power normalization). In this paper, STBC with 2Tx and 2Rx antennas are considered as a means of enhancing the performance and throughput of OFDM WLANs. In Alamouti's encoding scheme, two signals are transmitted simultaneously from the 2 transmit antennas. The transmission matrix is given by [10, 8]:

$$\mathbf{X} = \begin{bmatrix} x_{1,k} & -x_{2,k}^* \\ x_{2,k} & x_{1,k}^* \end{bmatrix} \quad (1)$$

where in the case of OFDM,  $x_{1,k}$  and  $x_{2,k}$  are the transmitted signals at a given subcarrier  $k$  (from two consecutive OFDM symbols) before being input to the IFFT and after the serial to parallel conversion of the modulated data [8]. STBC results apply for both HIPERLAN/2 and 802.11a.

### V. WLAN PHYSICAL LAYER RESULTS

After processing the channels obtained from the propagation modelling tool for the WLAN sites, link level simulations were performed. For each site, ~2000 CIRs corresponding to a mixture of line of sight and non line-of-sight points were obtained in a specified area around the AP. These channel realisations were then used to obtain an average PER performance for the given region. The mean rms. delay spread in the vicinity of AP1 (see Figure 8) was  $\tau_{rms}=55ns$  for the case of omni antennas and  $\tau_{rms}=28ns$  for the sectorised antennas.

Figures 1 and 2 respectively show PER results for AP1, for the case of omni and sectorised antennas for HIPERLAN/2. Figures 3 and 4 show the link throughput without and with sectorisation respectively. These results clearly demonstrate that performance is significantly enhanced by sectorisation. Especially, in channels with a dominant multipath component, the correct choice of sector reduces the multipath activity and improves the Rician statistics.

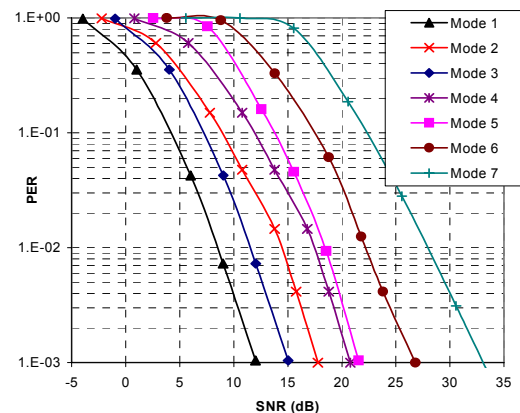


Figure 1. PER versus SNR for AP1 with omni antenna

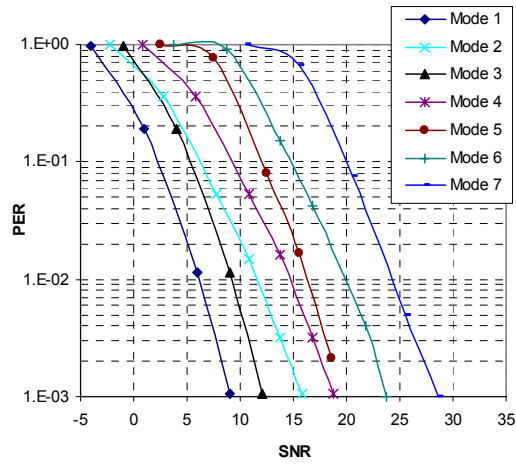


Figure 2. PER versus SNR for AP1 with sectorised antennas

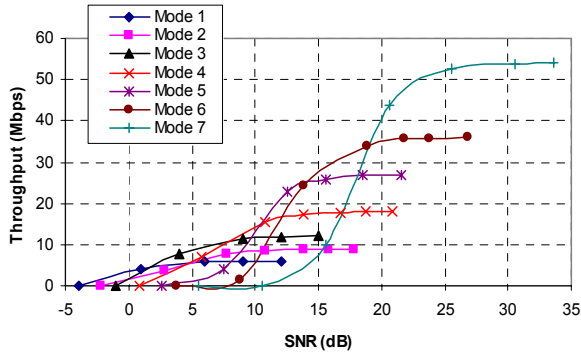


Figure 3. Link Throughput with omni antenna

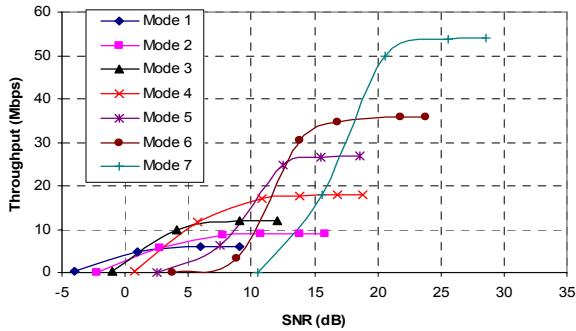


Figure 4. Link Throughput with Sectorised antennas

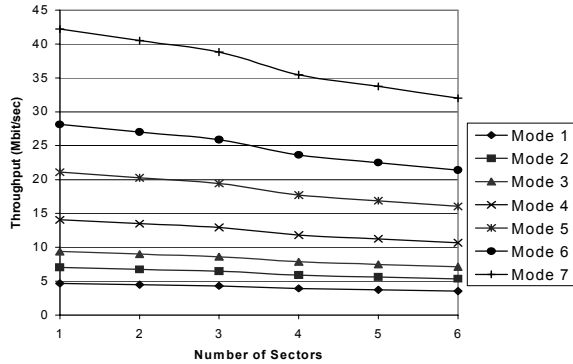


Figure 5. Maximum Throughput after the MAC for HIPERLAN/2 with Sectorised Antennas

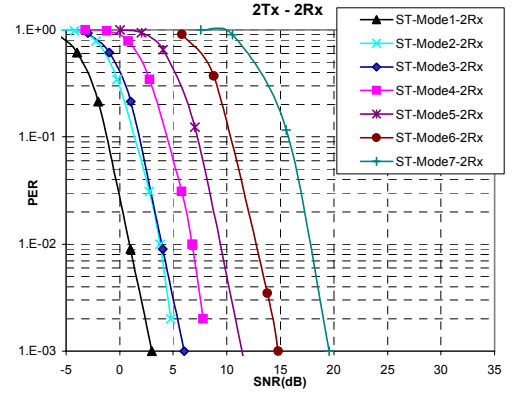


Figure 6. PER Performance using STBC with 2Tx, 2Rx.

The sectorisation improves performance by allowing the link adaptation mechanism to make use of higher modulation modes more frequently. Additionally, there is a sector gain which is not taken into account in the physical layer simulations. However, these benefits must be offset against the additional MAC overhead for the control sequences for each sector. Figure 5 shows the maximum throughput of each mode for different numbers of sectors. The maximum throughput after the MAC overheads for HIPERLAN/2 is 42Mbps for the case of omni antennas and only 32Mbps for the case of a 6 sector antenna. The maximum throughput after the MAC overheads for 802.11a depends on the packet size, and is 31Mbps for a packet size of 1500 bytes (for omni directional antennas) [2].

The use of STBC to enhance performance was also investigated. However, for this case uncorrelated wideband Rayleigh channels were assumed. Figure 6 shows the PER for the case of 2Tx and 2Rx antennas with STBC ( $\tau_{rms}=50ns$ —omni antennas). It can be seen that performance is significantly enhanced, providing gains of 8.5-10.5 dB depending on the mode. Figure 7 shows the link throughput with STBC.

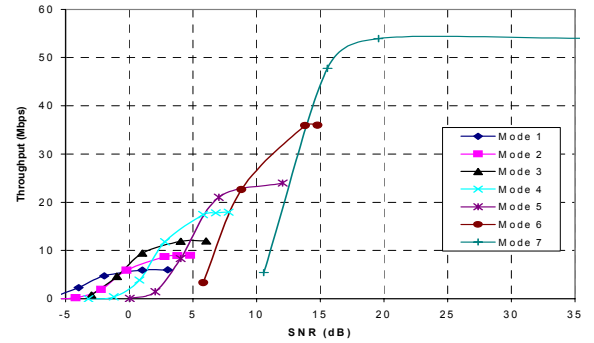


Figure 7. Link Throughput with STBC, 2Tx, 2Rx.

## VI. COVERAGE AND THROUGHPUT ANALYSIS

To map the throughput versus SNR results to achievable throughput in our site specific region it is necessary to relate the signal power at every location to an SNR value. To translate the received power to SNR, equation (2) was used where  $NF$  represents the noise figure (8dB),  $K$  is Boltzmann's constant,  $T$  is the temperature (290K) and  $B$  is the bandwidth:



$$SNR (dB) = Rx \text{ Power (dBm)} - KTB (dBm) - NF (dB) \quad (2)$$

The propagation modelling tool is employed to provide a point-to-multipoint analysis of the received signal level at 5.2GHz, in the outdoor WLAN environment for the AP locations. Based on the predicted coverage and the throughput performance of the WLANs, it is possible to evaluate the maximum achievable data rates throughout the coverage area for each location. The resulting output provides a unique insight into the maximum achievable hot-spot data rate at each location in the environment. Figure 8 shows the throughput achieved for HIPERLAN/2 with a transmit power of 23dBm and omni antennas for 3AP locations in Bristol [3]. Figure 9 compares the coverage for the case of omni and sectorised antennas for the case of AP1. Coverage maps for the sectorised case include the sector gain (of  $\sim 7.8$ dB), which is not taken into account in the physical layer results. Figure 10 shows the throughput for the case of omni directional antennas, sectorised antennas and a 2Tx-2Rx STBC system for AP1. The throughput maps include MAC overheads. It can be seen that the maximum throughput for the sectorised case drops to 32Mbps due to additional MAC overheads for antenna selection. However, the mean throughput over the whole area is enhanced. For the case of STBC the throughput is enhanced throughout the coverage area.

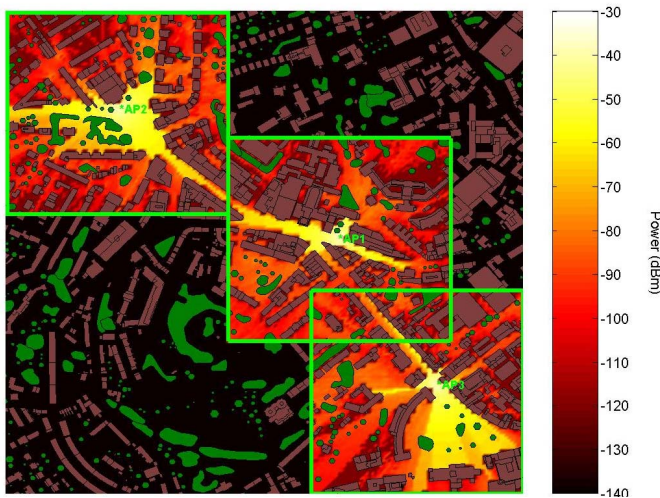


Figure 8. Throughput map for HIPERLAN/2- 23dBm.

The above results are further illustrated in Figure 11 which compares the coverage area for specific data rates. It can be seen that when employing a sectorised antenna, although the peak capacity (near the AP) is reduced due to the MAC overhead, capacity further away from the AP is actually enhanced due to higher K-factors and a stronger SNR. Hence sectorised antennas trade-off peak data rate for enhanced area coverage. Reducing the transmit power by 10dB still gives comparable coverage with the omni case – hence power savings can be made. STBC can provide better coverage with higher data rates than in the omni case without reducing the maximum throughput. However, the capacity enhancement in weak signal areas is not as good for the STBC case since the diversity improvement introduced by the Alamouti code is not as strong as the directive gain of the sectorised antennas.

## VII. CONCLUSIONS

In this paper channel data from a 3-D site-specific propagation model together with physical layer simulation tools have been used to simulate the coverage and throughput offered by WLANs to an integrated WLAN-3G system in a microcellular urban environment. Two cases have been examined for the WLANs: one case with sectorised antennas and the other with STBC. Coverage and throughput maps have been produced showing that significant enhancements can be achieved in both cases. The use of sectorised antennas has been shown to significantly increase the coverage area of the AP at the expense of the peak capacity. STBC, on the other hand, maintains a high peak capacity but also enhances the coverage area (but to a lesser extent). STBC are clearly suited for IEEE802.11a systems where the use of sectorised antennas is not supported. On-going work includes the translation of this extra throughput (introduced by the WLANs employing sectorised antennas or STBC) into capacity enhancement in a 3G/WLAN network similar to [3].

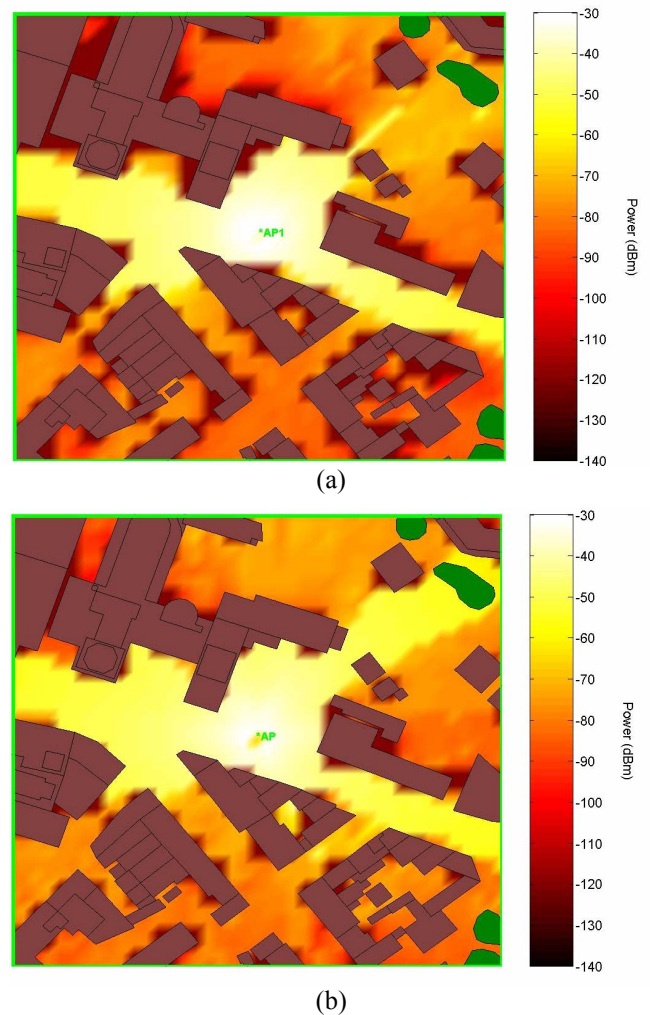


Figure 9. Coverage map with 23dBm transmit power for a) omni and b) sectorised antennas.

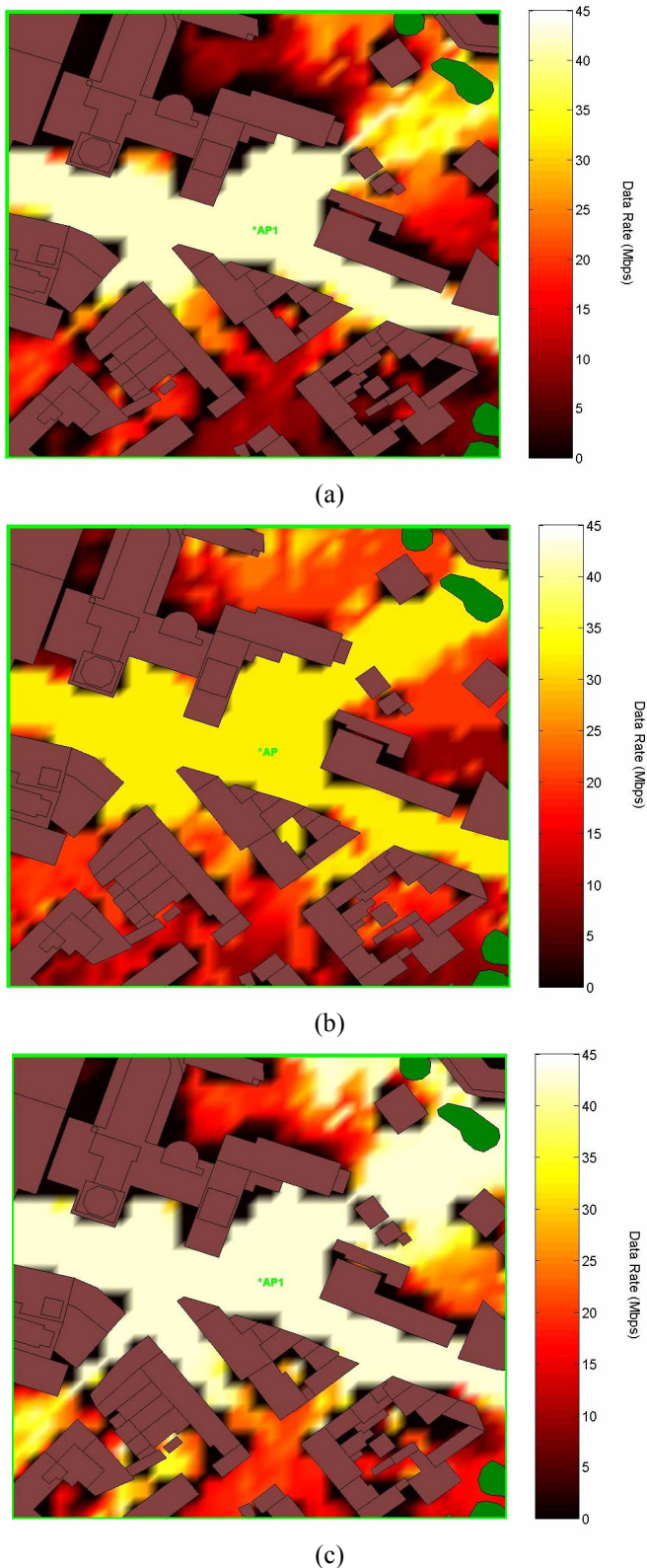


Figure 10. Throughput map for a) omni b) sectorised antennas and c) for STBC.

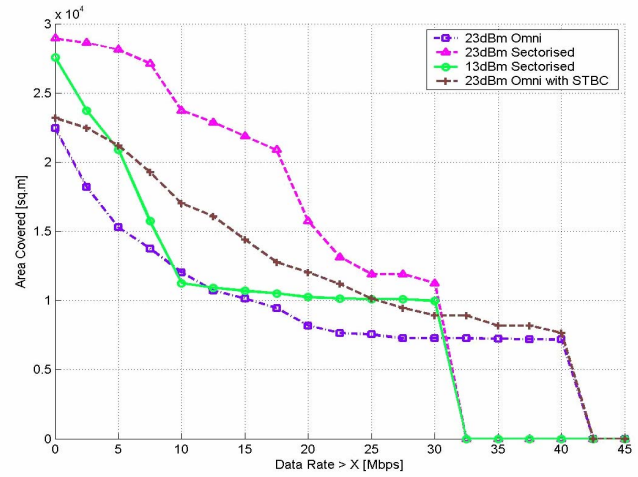


Figure 11. Area coverage comparison for all schemes

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## REFERENCES

- [1] ETSI, "Broadband Radio Access Networks (BRAN); HIPERLAN type 2 technical specification; Physical (PHY) layer," August 1999. <DTS/BRAN-0023003> V0.k.
- [2] A. Doufexi, S. Armour, P. Karlsson, M. Butler, A. Nix, D. Bull, J. McGeehan, "A Comparison of the HIPERLAN/2 and IEEE 802.11a Wireless LAN Standards," IEEE Communications Magazine, May 2002, Vol. 40, No. 5.
- [3] A. Doufexi E. Tameh, A. Molina, A. Nix, S. Armour "Hot Spot Wireless LANs to Enhance the Performance of "3G and Beyond" Cellular Networks", IEEE Communications Magazine, Vol.41 No.7, July 2003.
- [4] A. Doufexi, S. Armour, A. Nix, P. Karlsson, D. Bull, "On the Performance of HIPERLAN/2 Systems Using Sectorised Antennas," IEE Electronic Letters, Vol.37, February 2001.
- [5] J. De Vriendt, P. Laine, C. Lerouge, X. Xiaofeng, "Mobile network evolution: a revolution on the move", IEEE Communications Magazine, Vol.40, No.4, 2002, pp.104 -111.
- [6] A. Molina, G.E. Athanasiadou, A. Nix, "Cellular Network Capacity Planing Using the Combination Algorithm for Total Optimisation", IEEE VTC, Vol.3, Tokyo, Japan, May 2000.
- [7] E. K. Tameh, A.R Nix, "A Mixed-Cell Propagation Model for Interference Prediction in a UMTS Network", VTC Spring, Rhodes, May 2001.
- [8] A. Doufexi, S. Armour, A. Nix, M. Beach, "Throughput Enhancement of OFDM based WLANs Using Space Time Block Codes and Time Domain Least Squares Channel Estimation", EPMCC 2003, Glasgow.
- [9] A. Doufexi, S. Armour, P. Karlsson, A. Nix, D. Bull, "Throughput Performance of WLANs Operating at 5GHz Based on Link Simulations With Real and Statistical Channels", VTC Spring, Rhodes, May 2001
- [10] M. Alamouti, "A simple transmit diversity technique for wireless communications", IEEE Journal on Selected Areas in Communications, Vol. 16, No.8, October 1998.
- [11] V. Tarokh, H. Jafarkhani, A.R. Calderbank, "Space-time block coding for wireless communications: performance results", IEEE JSAC, Vol. 17 No. 3, March '99, pp.451-460.
- [12] IEEE Std 802.11a/D7.0-1999, Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High Speed Physical Layer in the 5GHz Band.
- [13] Lucent Press Release, "Lucent Offers Wireless In-Building" <http://www.3g.co.uk/PR/Dec2003/6188.htm>